Inductive sensor head for metal detectors

Publication number:	EP1092989
Publication date:	2001-04-18
Inventor:	GOLDER ROGER (GB); JONES PHILIP (GB)
Applicant:	HILTI AG (LI)
Classification:	
- international:	***G01V3/10;*** **G01V3/10;** (IPC1-7): G01V3/10
- european:	G01V3/10C3
Application number:	EP19990308054 19991013
Priority number(s):	EP19990308054 19991013

Also published as:

- US6437573 (B1)
- JP2001159685 (A)
- CA2321949 (A1)

Cited documents:

- WO9742527
- US2489920
- US5689184
- EP0222028
- FR2418469
- more >>

Report a data error here

Abstract of **EP1092989**

An inductive sensor head for detecting of ferrous or non-ferrous electrically conducting objects, in particular rebars in a surrounding medium like concrete or a brick wall, comprises as essential sensing elements at least one field coil (FI) with a small axial length compared to its diameter and at least one twin pair of sense coils (A, B) with a small diameter compared to the diameter of the field coil. The number of turns of wire on the field coil is small compared to the number of turns of wire on the sense coils. The common axis of the sense coils (A, B) is arranged perpendicular to the axis of the field coil so that there will be no component or a minimum component of maximum flux that is coaxial with the sense coils. For giving not only positional but also depths information, a twin pair of coaxially arranged identical field coils (F1, F2) is provided which are excitated time sequentially. In a center plane between the field coils an orthogonal arrangement of two twin pairs of sense coils (A, B and C, D) is provided enabling a three-dimensional hidden object positioning. The sensor head according to the invention can be automatically calibrated, controlled and read out under control of a microcontroller.

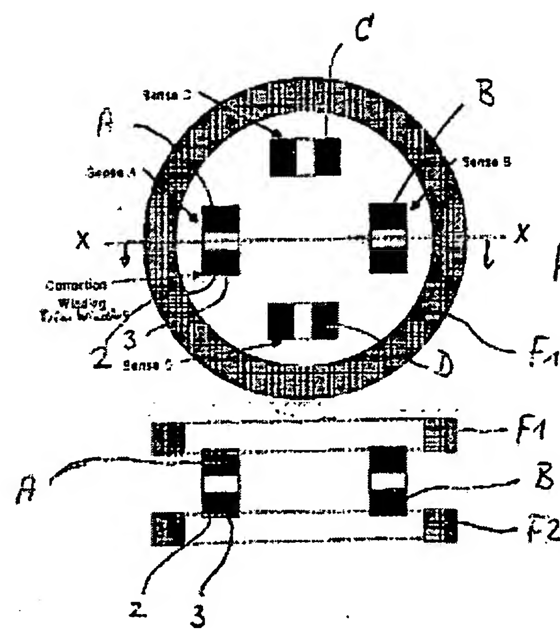

Fig. 6

---

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 092 989 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
18.04.2001 Bulletin 2001/16

(51) Int Cl.7: G01V 3/10

(21) Application number: 99308054.8

(22) Date of filing: 13.10.1999

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(71) Applicant: HILTI Aktiengesellschaft
9494 Schaan (LI)

(72) Inventors:
• Golder, Roger
Cambridge CB4 4DW (GB)
• Jones, Philip
Cambridge CB4 4DW (GB)

(74) Representative: Wildi, Roland et al
Hilti Aktiengesellschaft,
Feldkircherstrasse 100,
Postfach 333
9494 Schaan (LI)

(54) Inductive sensor head for metal detectors

(57) An inductive sensor head for detecting of ferrous or non-ferrous electrically conducting objects, in particular rebars in a surrounding medium like concrete or a brick wall, comprises as essential sensing elements at least one field coil (Fl) with a small axial length compared to its diameter and at least one twin pair of sense coils (A, B) with a small diameter compared to the diameter of the field coil. The number of turns of wire on the field coil is small compared to the number of turns of wire on the sense coils. The common axis of the sense coils (A, B) is arranged perpendicular to the axis of the field coil so that there will be no component or a minimum component of maximum flux that is coaxial with the sense coils. For giving not only positional but also depths information, a twin pair of coaxially arranged identical field coils (F_1, F_2) is provided which are excitated time sequentially. In a center plane between the field coils an orthogonal arrangement of two twin pairs of sense coils (A, B and C, D) is provided enabling a three-dimensional hidden object positioning. The sensor head according to the invention can be automatically calibrated, controlled and read out under control of a microcontroller.

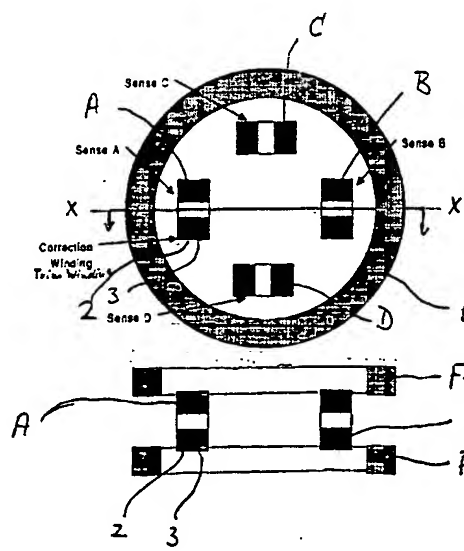

Fig. 6

Printed by Jouve, 75001 PARIS (FR)

Description

[0001] The invention relates to an inductive sensor head for detecting of a ferrous, ferric and/or non-ferrous electrically conducting objects buried in a surrounding medium.

[0002] Metal detectors for detecting ferrous or eventually non-ferrous objects in media like walls of concrete, brick, plaster or the like or in ground based on the disturbance or modulation of the inductive coupling between two coils are known in the art. US 5,729,143 describes a microprocessor controlled metal detector which uses in combination a transmitter coil providing a periodically varying magnetic field and a receiver coil connected thereto in an inductive bridge. The detector comprises means for balancing the two overlappingly arranged coils automatically and electronically for compensating of any initial coil misalignments or unwanted signals, in particular during an initial calibration step. In the known metal detector one of the coils, the field coil, is for generating an alternating magnetic field while the other coil, the sense coil, measures changes caused by a ferrous or non-ferrous material coming into the magnetic flux field while moving the detector over the medium containing the hidden disturbing object.

[0003] A problem with the known metal detectors is on the one hand the relatively large size which is unavoidable due to the side-by-side arrangement of the field coil and the sensor coil and on the other hand that the detector must be swept over a certain search area in a kind of scanning process.

[0004] It is an object of the invention to provide an inductive sensor head which is small in size and may be used as a hand-held tool or may be integrated into an electric, preferably hand-held tool like a drill hammer.

[0005] It is a further object of the invention to provide an inductive sensor head which provides sufficient clear information about a hidden ferrous or non-ferrous electrically conducting object without the necessity of sweeping the sensor head over a certain working area of the medium in which said object may be buried.

[0006] An inductive sensor head for detecting of ferrous or non-ferrous electrically conducting objects hidden in a medium is defined by the features of claim 1. Such a sensor head comprises at least one larger diameter field coil with a small axial length-to-diameter-ratio and at least one twin pair of coaxially arranged sense coils both having a small diameter compared to the diameter of the field coil. Preferably, the inductance of the or each sense coil is significantly higher than the inductance of the field coil. The higher the inductance the more sensitive the sense coil is to magnetic changes and the less gain is needed in the following amplifiers. The common axis of said twin pair of sense coils is extending perpendicular to the axis and in a diameter direction of the field coil, and said axis is positioned in a plane of the winding plane of said field coil or in a plane essentially parallel to the winding plane of that field coil. Further, the said two sense coils are positioned in an equal distance from the center of the field coil such that they are penetrated by the same magnetic flux direction of the flux field emanating from the field coil when excitated by an electric current.

[0007] Advantageous improvements and embodiments of the invention as defined in claim 1 are the subject-matters of further dependent claims.

[0008] For achieving better positional information, in particular for resolving depth information in relation to a hidden object, e. g., a reenforcing bar ("rebar" in the following) from a single position measurement cycle, a significant improvement of the concept of the invention is achieved if a twin pair of coaxially positioned field coils is provided. The mutual axial distance of said two field coils can be rather close and may preferably be less than their internal diameter. As a rule, the distance between the field coils is arranged such that the difference in magnetic field strength on a rebar is sufficiently large that it can be accurately measured. In addition, two twin pairs of sense coils with orthogonally arranged axes are positioned in a center plane parallel and approximately at half-way distance between the winding planes of said two field coils.

[0009] As will be described in the following in further details, the invention also provides an advantageous driving circuit for the said combination of a twin pair of field coils and a double twin-set of sense coils as defined in claim 3, wherein additional correction coils are provided in series connection with each of said two field coils in order to minimize magnetic offsets due to the fact that the sense coils cannot be or are difficult to exactly be positioned in the magnetic null position of both field coils.

[0010] The invention and advantageous details and embodiments thereof will be described in the following with reference to the accompanying drawings in which:

Fig. 1 depicts a basic arrangement of a field coil and a twin-set of sense coils in accordance with the invention;

Fig. 2 visualizes the magnetic flux in free space if an excitation current is passing through the field coil;

Fig. 3 visualizes how the magnetic field is distorted if a metal object is coming into the proximity of the magnetic field emanating from the field coil;

Fig. 4 is a diagram of the output voltage from each of the two sense coils in Fig. 1 if an object of a certain permeability (e. g. a rebar) is swept across the field and sensor coils arrangement of Fig. 2;

Fig. 5 depicts the basic concept of a coil configuration with two identical axially displaced field coils for achieving positional and depth information;

Fig. 6 shows the implementation concept of two field coils as shown in Fig. 5 and two orthogonally arranged twin pairs of sense coils for detecting of a hidden object at an arbitrary angle position within a

medium;

Fig. 7 visualizes the basic principle of a magnetic arrangement of the two field coils both additionally equipped with correction windings and trim windings as an adjustment means for magnetic flux correction;

Fig. 8 shows the circuit arrangement of a switching bridge for time sequential driving of a twin pair of field coils additionally provided with correction windings;

Fig. 9 shows a circuit configuration example of an amplification and multiplexing A/D-converting circuit for the output signal from the two twin pairs of sense coils of Fig. 6; and

Fig. 10 shows the basic structure of a complete control and read out system of an inductive sensor head according to the invention.

[0011] Throughout the various figures of the drawings the same reference signs are used for identical or corresponding parts.

[0012] The basic magnetic configuration for an induction sensor head according to the invention is shown in Fig. 1 and comprises a relatively large diameter field coil F with few turns of wire and an outer diameter of typically in the range of 40 to 80 mm and preferably between 60 and 70 mm. The term "few turns of wire" will be explained below. An AC current is passed to the field coil F to generate a magentic field as visualized in Fig. 2 by flux lines FL in free space. The magnetic flux field is measured using a twin pair of small diameter sense coils A, B having many turns of wire compared to the wire turn number of the field coil F. As shown by the schematic top and side views of Fig. 1, the twin pair of sense coils A and B is arranged on a common axis X-X which is oriented perpendicular to the central axis of the field coil F and extending through the diameter thereof. Accordingly, as shown in the lower side view presentation of Fig. 1, the sense coils A, B are arranged within the free space of the field coil F. As can be also seen from Fig. 1, the field coil F is of small axial length compared to its diameter. If no disturbance exists, the magnetic flux vector is parallel to the axis of the field coil F in the interior space encompassed by the field coil F. As the sense coils A and B are configured such that their common axis is perpendicular to the axis of the field coil F there will be no component of magnetic flux that is coaxial with said sense coils A and B, and hence no voltage will be induced in them.

[0013] If a metal object 1 (ferrous or non-ferrous), e. g., a rebar is brought or comes into the proximity with the field coil F as shown in Fig. 3, the magnetic field is distorted resulting in a component of the magnetic flux vector being coaxial with the sense coils A, B and hence inducing a voltage in the sense coils A, B. The magnitude of the voltage induced is a function of the size, composition and position of the disturbing metal object 1.

[0014] Bringing an object 1 with permeability (e. g. a ferrous rebar) into the magnetic field will cause a local increase in magnetic flux density which can be considered to twist the flux lines resulting in an induced voltage in the sense coils A, B. Non-ferrous conductive objects (e. g. copper) also disturb the magnetic flux field. This is believed to be due to induced eddy currents. Eddy currents will also be induced in ferrous conductors such as rebars, however, it is believed that the effects due to permeability dominate.

[0015] If the rebar, i. e. the object 1 is swept across the assembly in Fig. 3 from right to left, the output voltage from each of the sense coils A, B will be similar to the diagram of Fig. 4. The graph is the magnitude of the voltage from the sense coil as a rebar is swept over it. The Y axis is the magnitude of the voltage V and it has arbitrary units as it will vary with many geometric factors. The X axis is the sample number for the measurement and in this instance was 5 samples per mm movement.

[0016] For each sense coil A, B, the output voltage will be zero when the object 1 is directly over the center of the sense coil(s). From each sense coil we get an S curve shape as shown in Fig. 4. It is evident that the "S" curves for each of the sense coils A, B are displaced by the physical distance between the center line, i. e. the common axis of the sense coils A, B.

[0017] The coils configuration as explained above in connection with Fig. 1 to Fig. 4 will give a positional information for the disturbing object 1. For a given material of the object 1, the magnitude of the voltage V induced in the sense coils A, B is a function of the size of the object 1 disturbing the magnetic field and its position. However, it is not possible to resolve the depth of the object 1 from a single measurement. With the modified embodiment of the induction sensor according to the invention as described in the following with reference to Fig. 5 to 10 it becomes possible to also collect additional depth information from a single position measurement. The improvement is the use of a second field coil F_2 in addition to the first field coil F_1 which are indicated in Fig. 5 as "bottom field coil" and "top field coil", respectively. The two field coils F_1, F_2 are essentially identical and are therefore called a twin pair of field coils. The second or bottom field coil F_2 is coaxially arranged with the first or top field coil F_1 but axially displaced by a certain distance which usually is smaller than the inner diameter of the field coils F_1, F_2. This twin-set arrangement of two field coils F_1 and F_2 enables a second measurement that allows the depth of a disturbing object to be resolved. A certain disadvantage of this configuration arises from the fact that the sense coils A, B cannot be arranged in the magnetic null position of both field coils F_1, F_2.

[0018] Fig. 5 shows that the magnetic flux lines produced, e. g., by the first or top field coil F_1 are curved as they pass through the sense coils A, B, and hence there is a component of the magnetic flux vector coaxial with the sense coils A, B. This induces a voltage in the sense coils without the influence of a disturbing object 1, e. g.

a rebar.

[0019] The depth of an object 1 can be resolved by taking the ratio of the two received signals strenghts, one from each of the field coils F_1, F_2.

[0020] A further significant improvement is achieved by an implementation using a twin pair of two field coils F_1, F_2 and two orthogonal twin pairs of sense coils A, B and C, D, respectively, as shown in Fig. 6. The orthogonal pairs of sense coils A, B and C, D, respectively, allow the detection of, e. g., a rebar at an arbitrary angle position.

[0021] For the reason of clarity, where appropriate, in the following description only one twin pair of sense coils will be considered. In practice, however, the signal processing uses the vector sum of the signals produced by the two pairs of sense coils. Again, as in the case of Fig. 1, the outer diameter of the field coil twin pair F_1, F_2 may be in the range of 40 to 80 mm preferably between 60 and 70 mm, whereas the inner diameter of the field coils may be in the range of 30 to 70 preferably in the range of 45 to 55 mm. The axial distance of the two field coils F_1 and F_2 may be between 10 and 50 mm, preferably in the range of 15 to 40 mm and typically about 30 mm.

[0022] The winding depth and height of the field coils F_1, F_2 is typically about 4 to 10 mm and preferably about 7 mm. By the term "few turns of wire" as used in the beginning, a winding number of typically 50 to 250 turns and preferable 100 turns are to be understood resulting in an inductance value of about 1.5mH for a wire cross section of typically 0.5 mm. The DC resistance of such a field coil is typically in the range of 2 Ω.

[0023] As for the sense coils, the respective parameters are for the term "many turns of wire" used for the sense winding of about 2000 to 6000 turns, preferably about 4000 turns resulting for a wire diameter of 0.06 mm in an inductance value of 100mH. The DC resistance of such a sense coil is in the range of 800Ω, and the non-neglectable self-capacitance is about 20pF. The outer diameter of the sense coils is typically about 15 mm.

[0024] To reduce the cost of the field coils drive electronics and get a maximum $d\phi/dt$ a rectangular AC drive voltage is applied time sequentially to each of the field coils F_1 and F_2. Of course, due to the series resistance in the drive circuit and the inductance value of the field coils, the driving current is not a linear ramp.

[0025] Hence the voltages induced in the sense coils are not rectangular. Rather, the induced voltages are a function of the L/R time constants of the field coils F_1, F_2.

[0026] The induced offset voltage resulting from the sense coils A, B and/or C, D not being arranged in the magnetic null position of the field coils F_1, F_2 limits the possible pre-amplifier gain. To overcome this problem at least one correction winding 3 can be and should be added to the sense coils A, B, C and D, respectively. As will be further explained below in connection with Fig. 7 to Fig. 9, a fraction of the current excitating the field coils F_1, F_2 passes through each of such correction windings 3, such that the magnetic field generated by each of the correction windings cancels with that generated by the respective field coil in the vicinity of the sense coils. In addition, each of the sense coils is provided with a trim winding 2 so that each sense coil can be individually adjusted to a precise magnetic null position during calibration of the inductive sensor head. In Fig. 6, the correction winding(s) 3 and the trim winding 2 are only shown for sense coil A. However, it is to be understood that each of the sense coils A, B, C and D is provided with an identical correction winding(s) and trim winding, respectively, as shown in Fig. 9.

[0027] The magnetic diagram of Fig. 7 shows the various magnetic couplings between the field coils F_1, F_2 and the four sense coils A, B, C, D. As visualized by various double arrowed arcs there exists a magnetic coupling 10 between the upper, first field coil F_1 and the second, bottom field coil F_2, further an electromagnetic coupling 12 and 13, respectively, between the first and the second field coil F_1, F_2 and the sense coils A, B, C, D, which depends on the presence or absence of a disturbing object 1, e. g. a rebar, respectively, a still further coupling 14, 16 between the correction winding(s) 3 and each of the sense coils A, B, C, D as well as another coupling 15 between the sections of the correction winding(s) 3.

[0028] Considering for example a current I flowing into the upper, first field coil F_1 and one half of the correction winding 3. This current produces magnetic flux in each coil. The phase and coupling between the correction winding 3 and the sense coils A, B, C, D is such that the component of flux coaxial with the respective sense coil due to the field coil is cancelled in the vicinity of the respective sense coil. For reasons of simplicity and better understanding, the diagram of Fig. 7 only shows one correction winding 3 and one sense coil, e. g. sense coil A. In reality, however, and for the case of four sense coils, there will be four correction windings in series, one coupling to each associated sense coil as depicted in the schematic electric circuit diagram of Fig. 9. The first one of an inductively coupled pair of correction windings 3 from each of the four sense coil assemblies A, B, C and D, respectively, and one of the two field coils F_1 or F_2, respectively, are connected in series. The inductively coupled second part of the correction winding 3 from each of the four sense coils and the respective other field coil F_2 or F_1 are again connected in series. For each of the series connected arms, the phase of the correction windings 3 is set so that the sum of the fluxes from the correction winding 3 and the associated field coil approximately cancels in the vicinity of the sense coil. As there is no net flux coaxial with the sense coils no voltage is induced. When a disturbing object 1, i. e. a rebar is located in the vicinity of the field coils, the couplings 12 and 13 (Fig. 7) between the field coils F_1, F_2 and the respective sense coil is altered resulting in there being a net component of flux coaxial with the respective

sense coil. As there is a net flux coaxial with each of the sense coils, a respective voltage is induced. A subsequent excitation of the bottom, second field coil F2 by a current results in similar observations.

[0029] In practice, it is difficult to achieve the adjusting and component tolerances necessary to arrive at a magnetic null at each of the sense coils without some precise and individual adjustment. Therefore, in the embodiment of Fig. 6 and the circuit arrangement of Fig. 9 as well as in the magnetic arrangement of Fig. 7 a further adjustment may be provided by the addition of an extra trim winding 2 on each of the sense coils A, B, C and D, respectively. A small adjustable fraction of the field coil current is passed in each of the trim winding 2 and its magnitude is controlled by a microcontroller 40 (Fig. 8). By changing the magnitude of the trim current by the microcontroller 40 the ratio of the flux from the respective field coil and the sum of the fluxes from the correction windings 3 and trim windings 2 cancel in the vicinity of each of the sense coils.

[0030] The circuit diagrams of Fig. 8 and 9 show the main components of a field coil driver bridge 41 and sense amplifier 42 followed by a multiplexed A/D- converter 30 as a signal input source for microcontroller 40. A display and further user buttons are not shown in the drawings of Figs. 8 and 9.

[0031] In the circuit of Fig. 8 the two field coils F_1, F_2 in electrical series connection with the associated correction winding(s) 2 are driven by a 4-FET switching bridge. As only one of the field coils is driven at a time part, the switching bridge may share common components to save cost. In Fig. 8, the center arm of the bridge 41 is common to both field coils F_1, F_2 and is always driven by the microcontroller 40. To generate a current in field coils F_1 or F_2, the right or left arms of the bridge are driven by the microcontroller 40.

[0032] As shown in Fig. 9 for each of the four sense coils A, B, C, D there is a sense amplifier 42 having a gain of approximately 50 times. The outputs of the sense amplifiers 42 are supplied to plural input-port A/D-converter 30 which is multiplexed to time-sequentially read the outputs of the four sense amplifiers 42.

[0033] The depth of a disturbing object 1, i. e. a rebar may be determined by the use of a prestored knowledge base. The knowledge base is the result of measuring many rebars of different diameters at coverage depths from for example 10 mm to 100 mm. To determine the cover or depth of a rebar the following process steps are performed:

S1 Measure the signal strength from each sense coil pair when excitating the bottom, (second) field coil F_2;

S2 Measure the signal strength from each sense coil when excitating the upper, (first) field coil F_1;

S3 Use these two results as an idex for accessing the depth reading from a pre-stored knowledge base array; and

S4 Display the result retrieved from the array.

[0034] Fig. 10 shows an overall-view for the arrangement and implementation of an inductive sensor head according to the invention with the significant advantage that a hidden object 1 can be located in a horizontal plane but also with respect to its approximate depth within a certain cover range. As shown in Fig. 10, the microcontroller 40 receives the sense coils measuring values via the multiplexed A/D-converter 30. During a pre-measurement calibration step, the digitally controlled trim currents for the trim windings 2 are adjusted to optimize the coupling of the correction winding(s) 3. The microcontroller 40 also initiates and controls the field coils drive electronics as for example shown in Fig. 8. For the purpose of clarity, in Fig. 10 only one twin pair of sense coils A, B is shown.

Claims

1. An inductive sensor head for detecting of a ferrous or non-ferrous electrically conducting object (1) burried in a surrounding medium **comprising**:

   - at least one field coil (F) having a small axial length-to-diameter ratio;
   - at least one twin pair of co-axially arranged sense coils (A, B) with small diameter compared to the diameter of the field coil (F) and an inductance higher than that of said field coil (F), the common axis thereof being oriented orthogonal to the axis and in a diameter direction of said field coil (F) and in a plane of or essentially parallel to the winding plane of said field coil (F), said sense coils (A, B) being positioned equal distant from the center of said field coil (F) and within the same magnetic flux direction emanating from said field coil (F) when excitated by an electric current.

2. The sensor head of claim 1, wherein the common axis of said twin pair of sense coils (A, B) is positioned in the winding plane of said field coil (F) and both sense coils are arranged within the free space of the field coil.

3. The sensor head of claim 1, wherein a twin pair of coaxially positioned field coils (F_1, F_2) is provided with a mutual distance, and two twin pairs of sense coils (A, B, C, D) with orthogonally arranged axes are positioned in a center plane parallel to and at approximately half distance between the winding planes of said two field coils.

4. The sensor head of claim 3, wherein an inductively coupled twin pair of correction windings (3) is added on at least one of said sense coils, one correction

winding each of said twin pair being arranged in electric series connection to an associated one of said field coils such that in a calibration state of the sensor head the magnetic field generated by said correction windings essentially cancels with that generated by the field coils in the vicinity of the sense coils.

5. The sensor head of claim 3 or claim 4, wherein a drive circuit for time sequential excitation of said field coils is provided.

6. The sensor head of claim 5, wherein said drive circuit comprises a switching bridge (41), one arm thereof consisting of a series connection of said two field coils and the respective correction windings (3), the common coupling point of said correction windings being connected to the coupling point of two series-connected switches forming the other arm of said switching bridge.

7. The sensor head of claim 4, wherein a trim winding (2) is provided on each of said sense coils (A, B, C, D) to which a small adjustable fraction of the field coil current is supplied under control of a microcontroller (40) for changing the magnitude of the respective trim currents such that the ratio of the magnetic flux from the respectivly excitated field coil and the sum of the fluxes from the correction windings (3) and the trim windings (2) cancel in the vicinity of each of the sense coils.

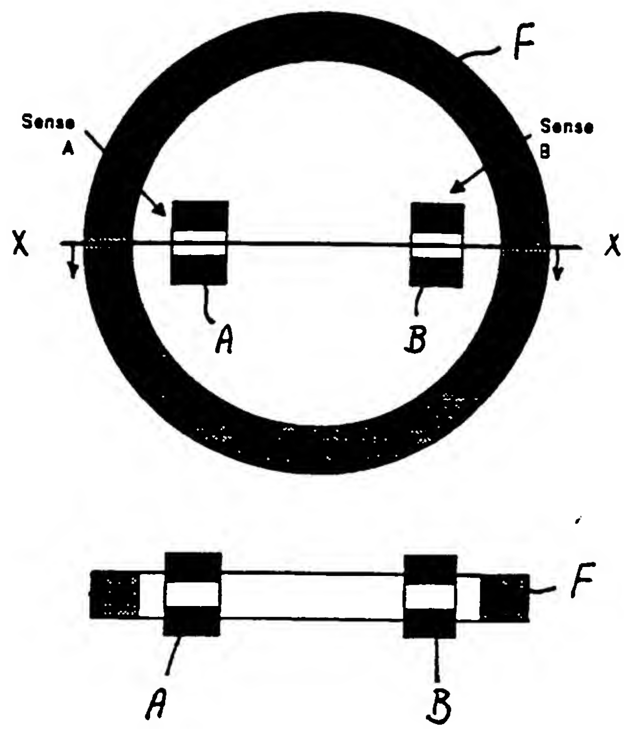

Fig. 1

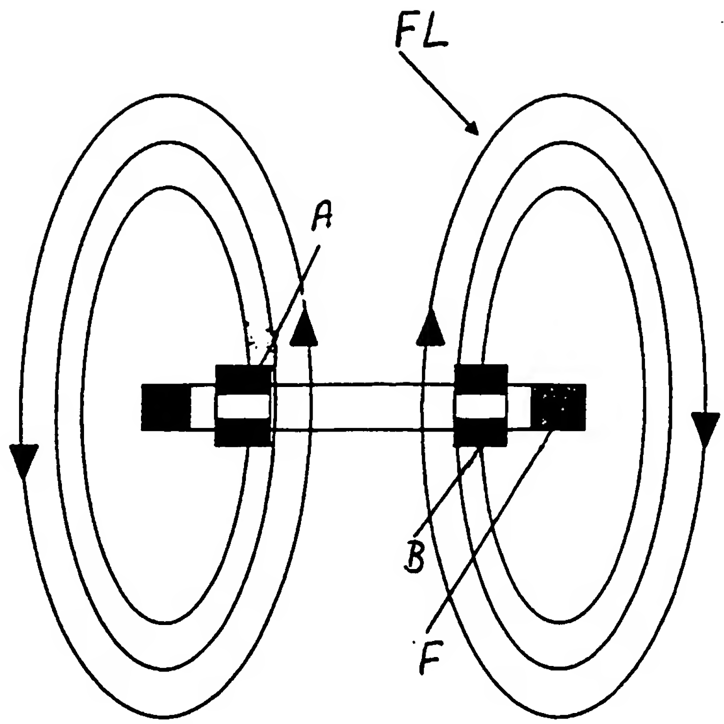

Fig. 2

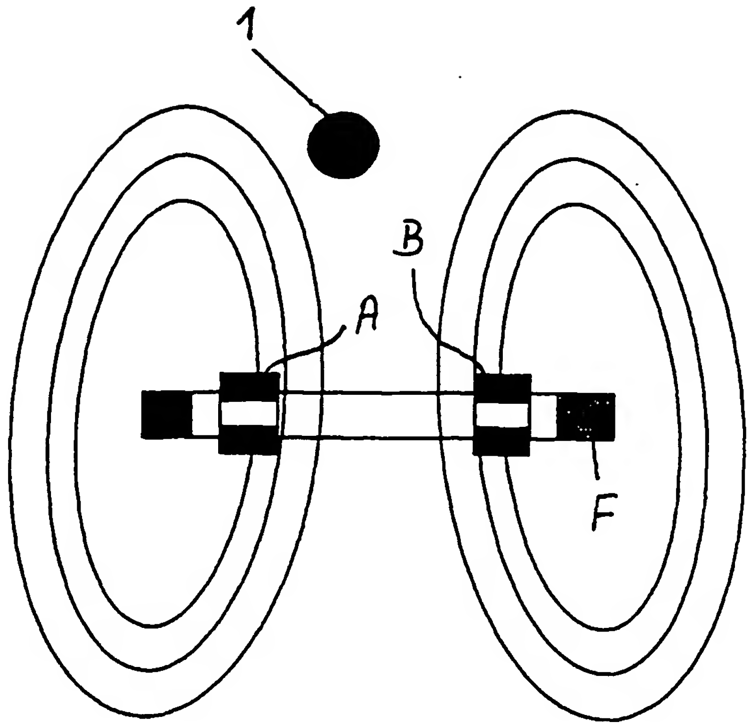
1
A
B
F

Fig. 3

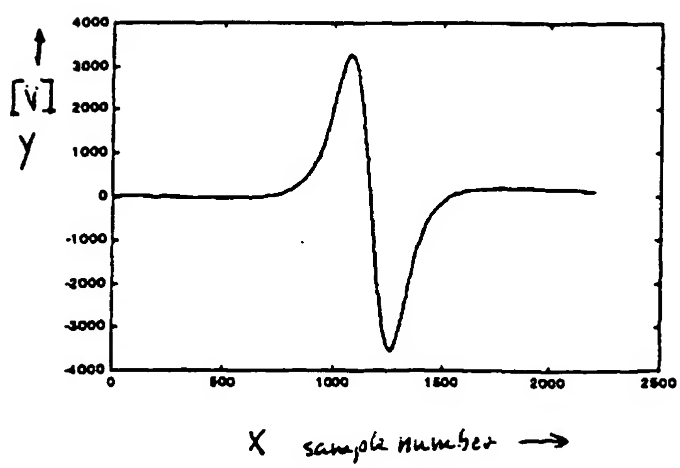
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
0
500
1000
1500
2000
2500
[V]
y
X sample number

Fig. 4

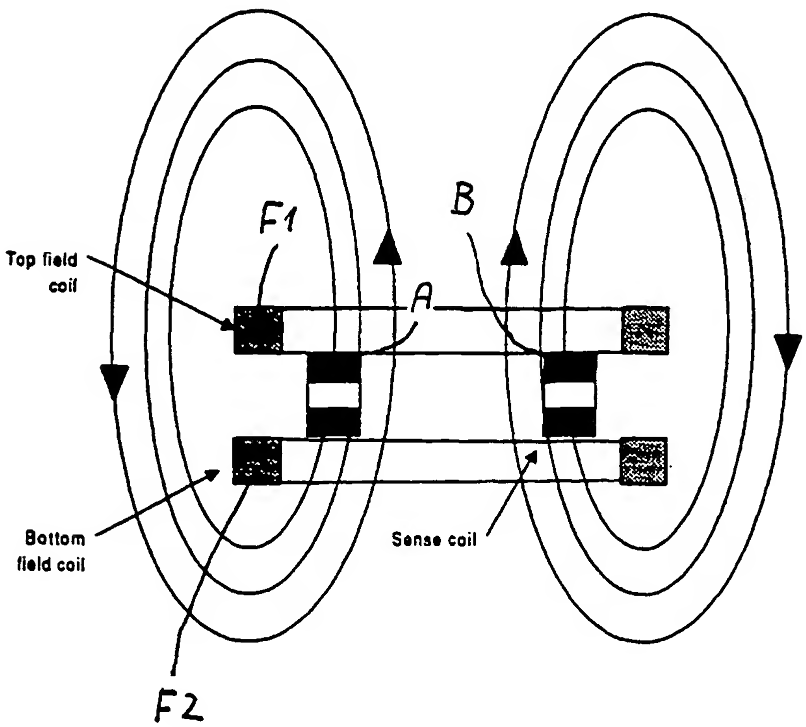
F1
B
Top field
coil
A
Bottom
field coil
Sense coil
F2

Fig. 5

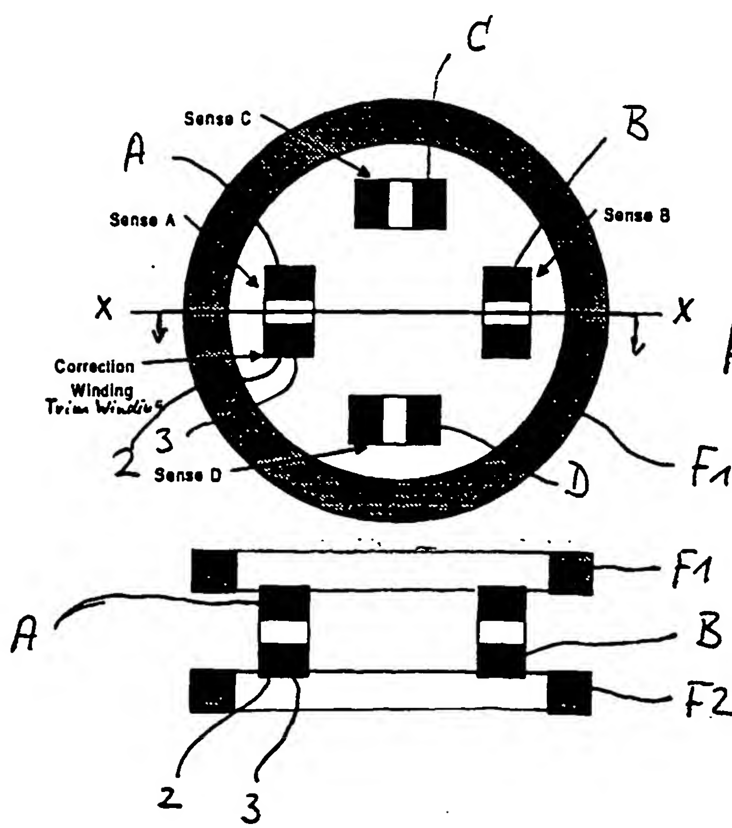
C
Sense C
A
B
Sense A
Sense B
X
X
Correction
Winding
Trim Winding
3
2
Sense D
D
F1
F1
A
B
F2
2
3

Fig. 6

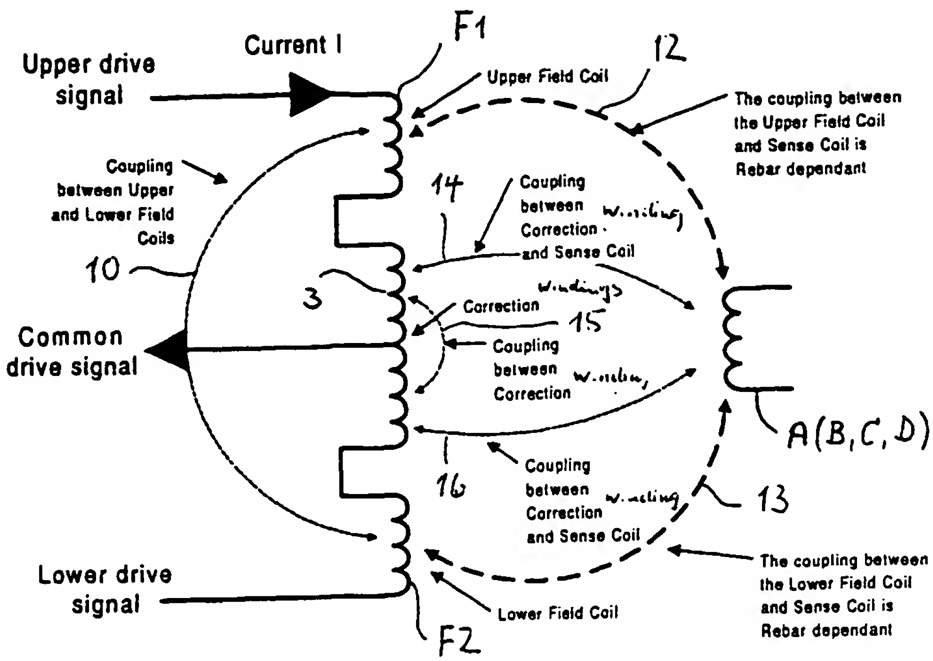
Upper drive signal
Current I
F1
Upper Field Coil
12
The coupling between the Upper Field Coil and Sense Coil is Rebar dependant
Coupling between Upper and Lower Field Coils
14
Coupling between Correction winding and Sense Coil
10
3
Correction windings
15
Coupling between Correction winding
Common drive signal
A(B,C,D)
16
Coupling between Correction winding and Sense Coil
13
The coupling between the Lower Field Coil and Sense Coil is Rebar dependant
Lower drive signal
Lower Field Coil
F2

Fig 7

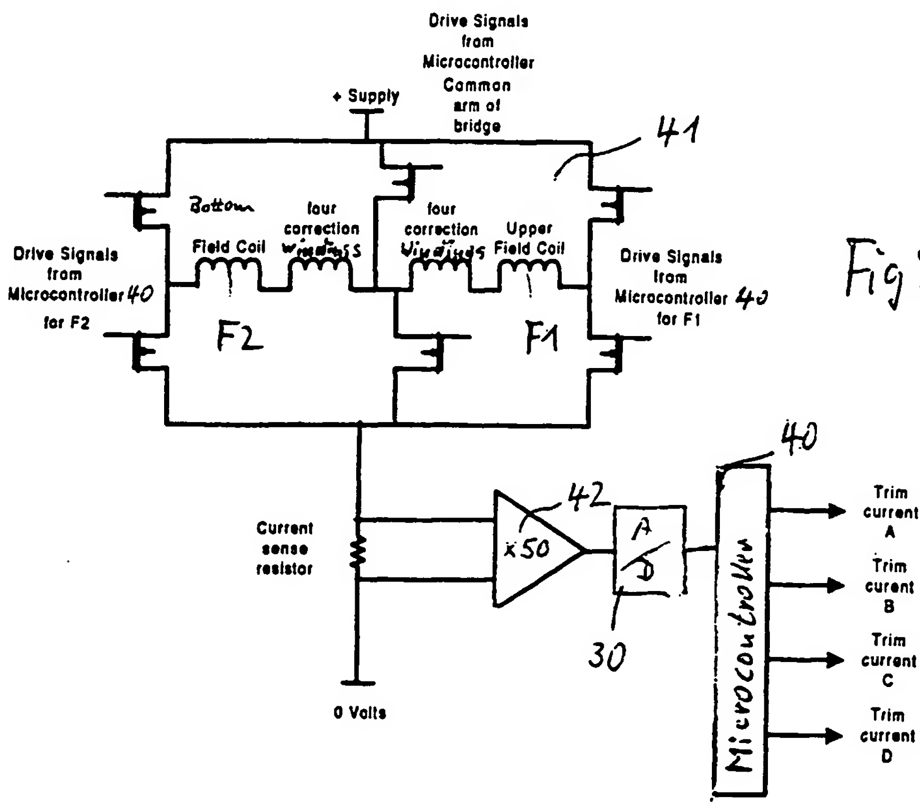
Drive Signals from Microcontroller Common arm of bridge
+ Supply
41
Bottom Field Coil
four correction windings
four correction windings
Upper Field Coil
Drive Signals from Microcontroller 40 for F2
F2
F1
Drive Signals from Microcontroller 40 for F1
40
42
Current sense resistor
x50
A/D
30
Microcontroller
Trim current A
Trim curent B
Trim current C
Trim current D
0 Volts

Fig 8

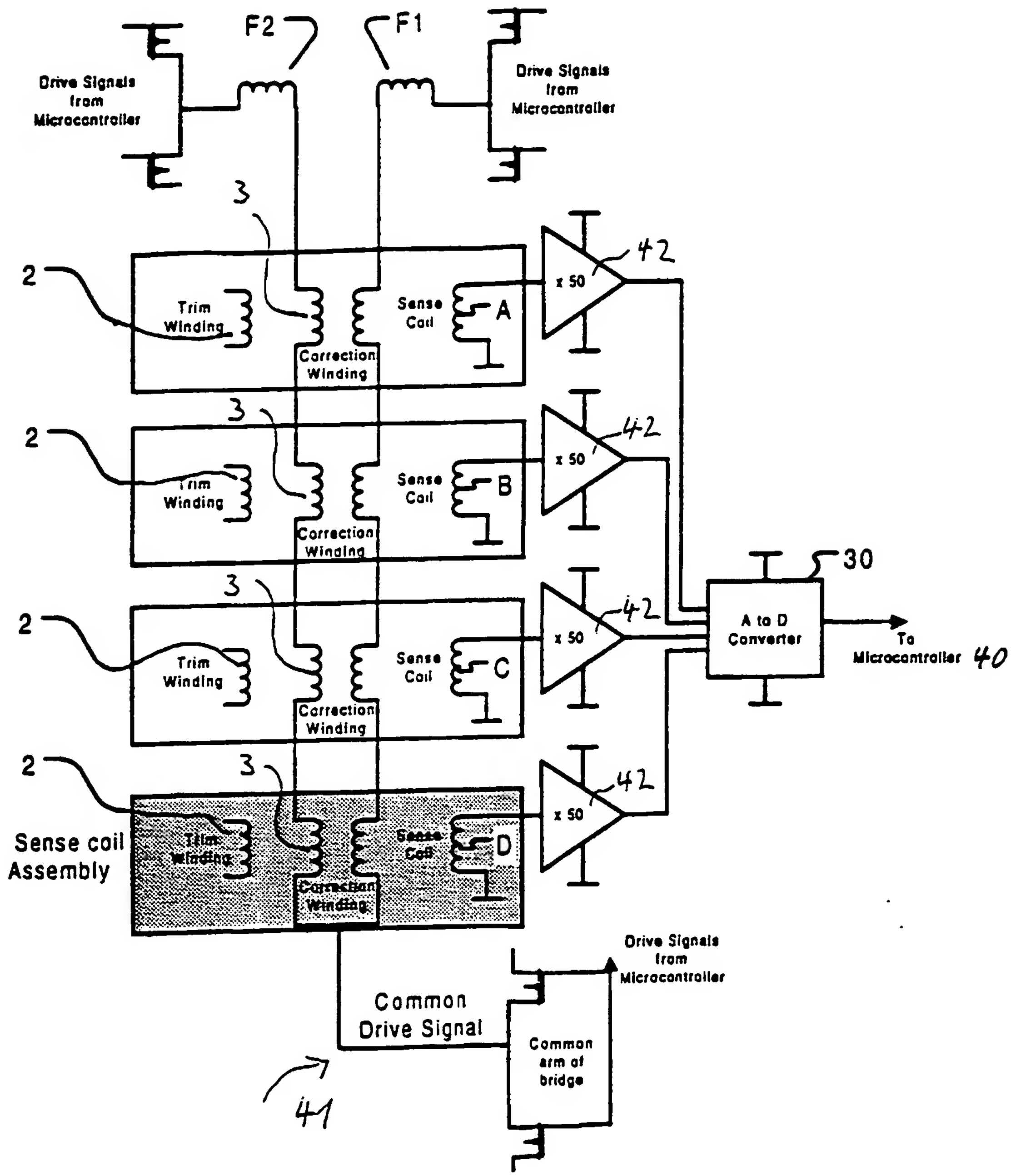
F2
F1
Drive Signals from Microcontroller
Drive Signals from Microcontroller
3
2
Trim Winding
Correction Winding
Sense Coil
A
B
C
D
x 50
42
30
A to D Converter
To Microcontroller
40
Sense coil Assembly
Common Drive Signal
Drive Signals from Microcontroller
Common arm of bridge
41

Fig. 9

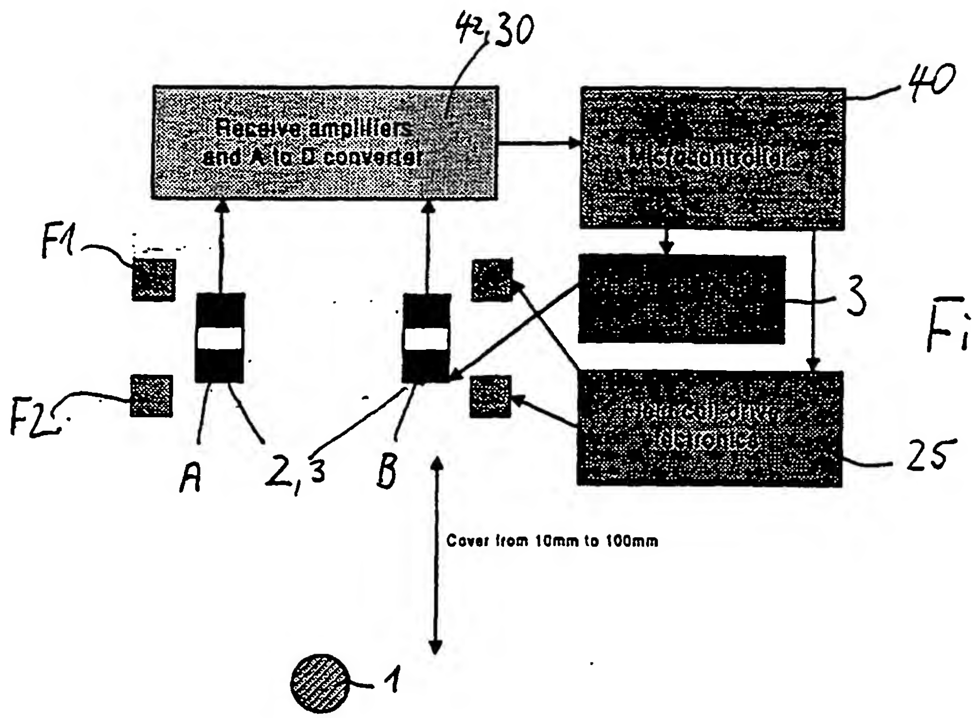
42,30
Receive amplifiers
and A to D converter
40
3
25
F1
F2
A
2,3
B
Cover from 10mm to 100mm
1

Fig. 10

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 99 30 8054

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	WO 97 42527 A (PLUS ENTERPRISE INC) 13 November 1997 (1997-11-13) * page 2, line 23 - page 3, line 13 * * page 5, line 19 - page 6, line 12; claim 1; figure 1 *	1	G01V3/10
A	US 2 489 920 A (PHILIP C. MICHEL) 29 November 1949 (1949-11-29) * column 1, line 1 - line 15 * * column 6, line 40 - line 75; figure 2 *	1,2	
A	US 5 689 184 A (JAGIELINSKI TOMASZ MAREK ET AL) 18 November 1997 (1997-11-18) * column 2, line 29 - line 60 *	1	
A	EP 0 222 028 A (VALLON GMBH) 20 May 1987 (1987-05-20) * column 3, line 10 - line 47; claim 1; figure 2 *	1,2	
A	FR 2 418 469 A (COGEMA) 21 September 1979 (1979-09-21) * page 2, line 1 - line 18 * * page 3, line 5 - line 37 *	1,4	TECHNICAL FIELDS SEARCHED (Int.Cl.7) G01V
A	US 2 807 777 A (HENRI-GEORGES DOLL) 24 September 1957 (1957-09-24) * column 4, line 1 - line 32; figure 3 *	1	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	28 March 2000	Lorne, B

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 99 30 8054

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

28-03-2000

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
WO 9742527	A	13-11-1997	US	5726628 A	10-03-1998
			AU	2713697 A	26-11-1997
US 2489920	A	29-11-1949	NONE		
US 5689184	A	18-11-1997	NONE		
EP 0222028	A	20-05-1987	FI	854742 A,B,	03-05-1987
			US	4779048 A	18-10-1988
FR 2418469	A	21-09-1979	CA	1143009 A	15-03-1983
			US	4277750 A	07-07-1981
US 2807777	A	24-09-1957	NONE		

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82